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CORRECTION SHEET

Development of Explosives - Metallized Explosives

Project No.: TA3-5001G

Report No.: 1

PA Memorandum Report No.: MR-44

Date: 30 Sept 1953

In Tables Ia, Ib, and Ic and in Figures 8 and 9 of PA Memorandum Report No. MR-44, the rate of detonation value for TNT should read 6708 meters/second instead of 7708 meters/second as reported.

PICATINNY ARSENAL
TECHNICAL DIVISION

MEMORANDUM REPORT

SUBJECT: DEVELOPMENT OF EXPLOSIVES, METALLIZED

REPORT NO. MR-24

PREPARED BY G. E. SHENFIELD DATE 30 SEPTEMBER, 1953

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DEVELOPMENT OF EXPLOSIVES - METALLIZED EXPLOSIVES

Project No. TA3-5001G

Report No. 1

Picatinny Arsenal Memorandum Report No. 44

Date: 30 Sept 1952

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Agency Authorizing Work: OCO - ORDTA

Project No   :   TA3-5001G

Project Title: Development of Explosives - Metallized Explosives

OBJECT

To investigate the properties of explosives containing aluminum or other oxidizable matter and their effect on blast characteristics.

ABSTRACT

An investigation of some thirty metals, alloys or metallic compounds in admixtures with TNT indicated that tin, magnesium-aluminum alloy, titanium hydride, and zirconium hydride should be of interest as additives in place of aluminum in Tritonal. Many of the relationships between performance in terms of brisance or power and readily determined or calculated thermochemical properties, which have been shown to exist with pure explosives, were somewhat obscure when applied to TNT-metal mixtures. Measurements of actual peak pressures developed from unconfined cylindrical charges detonated in air confirm the prediction that tin appears worthy of further study. Tests of the other promising additives in admixtures with TNT should be conducted using spherical charges.

The direct substitution of magnesium-aluminum alloy for aluminum in Torpex, resulted in a castable mixture having explosive properties and power comparable to standard Torpex. From the standpoint of improved stability, such a substitution was indicated to be desirable. Modified Torpex-type compositions containing up to 35 percent by weight of aluminum were castable at $95^{\circ}C$. A coarse, atomized aluminum powder permitted a greater amount of RDX in the mixture than the finer specification material. However, on the basis of the explosive properties determined and the thermodynamic power calculated, none of the variations of Torpex studied in which the proportions of the ingredients were changed would be superior to standard Torpex. Actual blast measurements of their effectiveness in open-air will be made to confirm the above conclusions.

INTRODUCTION:

1. The addition of aluminum to increase the power of explosives was proposed by Escales in 1899 and patented by Roth in 1900 (German Patent 172,327). Some recent studies directed towards establishment of the optimum amount of aluminum for the maximum power from TNT/Al explosives, have shown that (1) the blast effect increased to a maximum when the aluminum content was 30 percent (Ref A); (2) the brisance, as measured by the Sand Test, passed through a maximum at about 17 percent aluminum (Ref B); (3) in Fragmentation Tests, no maximum was observed: additions of aluminum caused a decrease in fragmentation efficiency over the entire range from 0 to 70 percent aluminum content (Ref C), and (4) the rate of detonation of cast charges was continuously decreased by additions of aluminum up to 40 percent (Ref D). For all practical purposes, it was concluded that the addition of 18 - 20 percent of aluminum to TNT improved its performance to a maximum. This conclusion was in agreement with that of British investigators who measured performance of aluminized mixtures based on extensive Lead Block Test data (Ref E).

2. It was considered desirable that a preliminary study be made for the purpose of finding other metal additives equal to or better than aluminum in explosives. The addition of 20 percent of selected metals, alloys or metallic compounds as a direct replacement for the aluminum in 80/20 Tritonal, rather than the stoichiometric amounts based on assumed reactions, was chosen because this percentage approached the maximum amount which produced readily castable mixtures in the temperature range normally used for pouring. X-ray analysis of cast charges showed that when amounts greater than 20 percent of high density materials were added to TNT, segregation, cavitation and piping occurred much more frequently (Ref D).

3. The study of additives which were indicated to improve the performance of TNT, is being extended to include Torpex-type compositions. Variations considered in the Torpex formulation were (1) metallic additives other than aluminum, (2) different granulations of RDX and aluminum, and (3) various percentages of RDX and aluminum, all with the aim of producing castable compositions which might be expected to have improved blast properties.

4. This report, therefore, covers two phases of a laboratory investigation directed towards an evaluation on the basis of small-scale tests of both modified 80/20 Tritonal (Part I) and modified Torpex (Part II).

DISCUSSION:

Part I

5. The effect of aluminum in explosive mixtures is attributed chiefly to the heat evolved in its oxidation. A further advantage lies in the fact that the Al_2O_3 formed may not remain as a solid but vaporizes to a gas which increases the over-all volume of gas and pressure developed by the explosive. The boiling point of Al_2O_3 is only $2900°C$ while the temperature developed on explosion of aluminized mixtures is usually above $4500°C$. This fact may account for the increases noted.

6. The physical characteristics of the shock wave around an explosive are described by giving the peak pressure and impulse at various distances. The peak pressure gives a measure of the maximum force which would be exerted against a structure (pressure x area = force); the impulse gives a measure of the force times the duration which, for an unsupported structure, is proportional to the velocity which would be given the structure. The following data have been collected to show peak pressures and impulses for aluminized explosives in comparison with those values for non-aluminized explosives (Ref F). It should be noted that the pressure-time curves of aluminized explosives have higher "peaks", and the pressures do not fall as quickly as those which are non-aluminized.

Aluminized Explosives

Composition, %	DBX	Minol-II	Torpex-II	HBX	80/20 Tritonal	Baronal
TNT	40	40	40	40	80	35
RDX	21	--	42	42	--	--
Ammonium nitrate	21	40	--	--	--	--
Aluminum	18	20	18	18	20	15
Barium nitrate	--	--	--	--	--	50
Wax, % added	--	--	--	5	--	--

Ballistic Mortar

	DBX	Minol-II	Torpex-II	HBX	80/20 Tritonal	Baronal
% TNT	146	143	138	133	124	96

Open-Air Blast (TNT in tests = 100 for reference)

	DBX	Minol-II	Torpex-II	HBX	80/20 Tritonal	Baronal
Peak Pressure	118	115	122	115	110	110
Impulse	127	116	125	118	115	112
Energy	138	133	146	--	119	--

Non-Aluminized Explosives

Composition, %	PTX-2	Comp B	PTX-1	50/50 Pentolite	50/50 Amatol
TNT	28	40	20	50	50
RDX	44	60	30	--	--
PETN	28	--	--	50	--
Tetryl	--	--	50	--	--
AN	--	--	--	--	50
Wax, % added	--	1	--	--	--

Ballistic Mortar

	PTX-2	Comp B	PTX-1	50/50 Pentolite	50/50 Amatol
% TNT	138	133	132	126	124

Open-Air Blast (TNT in tests = 100 for reference)

	PTX-2	Comp B	PTX-1	50/50 Pentolite	50/50 Amatol
Peak Pressure	113	110	111	105	97
Impulse	113	110	109	107	87
Energy	--	116	--	--	--

7. The measurement of pressure-time curves or blast characteristics generally requires special gages, an electronic instrumentation system, and several pounds of an explosive charge. These tests are expensive and time consuming. In order to decrease the costs involved it was felt that small-scale tests of other explosive characteristics might serve for preliminary evaluation of experimental mixtures. A further aim would be to establish where possible, correlation between readily determined or calculated explosive properties and the more difficulty determined blast properties. Using relationships between Sand Test values and air blast results previously determined (Ref G), there are tabulated in Table I some measured explosive properties and calculated blast data for TNT containing various metallic additives. These blast data were calculated by means of equations derived from least squares formulas (Fig 1). Since existing Sand Test data are obtained on samples having equal weight rather than equal volume, the conversion factor

$$X = 1.14X' - 16.8$$

Where X = Sand Test x density (Volume basis)
and X' = Observed Sand Test x loading density (cast)

was derived and applied to measured Sand Test values. The validity of such empirical relationships was tested with the following explosives for which both measured Sand Test and measured blast data were available:

Explosive	Peak Pressure		Impulse [a]		Energy [a]	
	Calc	Obs [a]	Calc	Obs [a]	Calc	Obs [a]
HBX	118	115	122	118	136	---
50/50 Pentolite	113	105	116	107	126	---
PTX-1	112	111	115	109	123	---
PTX-2	116	113	120	113	132	---
RDX Comp C-3	107	105	108	109	112	---
Avg Deviation		$\pm$ 3.4		$\pm$ 5		
Avg % Deviation		$\pm$ 3.1		$\pm$ 4.3		

[a] Data taken from Ref F.

8. The effect of the addition of 20 percent of metals, alloys or other addends on the sensitivity and stability characteristics of TNT (Table I) served to eliminate certain mixtures from further study. For reasons of undue sensitivity to impact, the following materials were eliminated:

    a. Boron, amorphous
    b. Silicon nitride
    c. Zirconium phosphate

Only titanium was eliminated because of instability or sensitivity to heat. The following were not considered for further study due to their excessive cost at the present time:

    a. Boron, amorphous
    d. Aluminum borate
    e. Boron nitride

Beryllium, in addition to being quite expensive even when contained in alloys, should be avoided as a component of explosive mixtures since its toxic and hazardous properties are known (Ref H). For various other reasons, particularly due to unavailability of sufficient material tests of the effect of the following addends were not completed:

    f. Aluminum-silicon alloy
    g. Calcium silicide
    h. Ferrovanadium
    i. Magnesium silicide
    j. Stainless steel
    k. Titanium cyanonitride

Addends to TNT which appear of interest (Table I), in addition to aluminum, include tin, titanium hydride, zinc, zirconium hydride and zirconium-nickel alloy.

9. A summary of thermochemical properties of various metals, alloys, or metallic compounds in admixtures with TNT is given in Table II. The method of calculating oxygen balance, heat of combustion, heat of explosion and power has been described in detail (Ref J). The metal oxides used in these calculations were in general those which correspond to the predicted valence given by the periodic table. Calculated heat of combustion values are in close agreement with values determined experimentally in the Parr Bomb. Calculated heat of explosion values were in all cases higher than the determined values, several of which were about double those obtained in Parr Bomb tests. These data, plus the slightly lower calculated gas volumes, indicate that the course of the explosive reaction and the products formed may not be as assumed. However, plot of these data showed an apparent correlation between all calculated values and those determined by standard experimental methods.

10. The increase in power resulting from the addition of metals to explosive compounds which are already deficient in oxygen, requires further explanation. Metals being strong oxygen acceptors, first produce their oxides and thus reduce the oxygen available for conversion of carbon to carbon dioxide. Other gases formed are hydrogen and nitrogen, but the total volume of gases is reduced by the formation of nongaseous solids. Although the gas volume is reduced, there is a corresponding increase in the heat of explosion due to the high heat of formation of metal oxides. This observation no doubt led Berthelot to combine these quantities in an expression called the "Berthelot Product" or calculated power $= \Delta V \times H_E$,

Where ΔV = volume of gases (cc)/gm explosive
        H_E = heat of explosion in cal/gm

This product, calculated from determined gas volumes and determined heat of explosion values, was not related to Ballistic Mortar in a manner similar to that shown for pure explosive compounds (Fig 2). However, a plot of Ballistic Mortar as a function of power derived from calculated gas volume and heat of explosion was, with few exceptions, practically linear (Fig 3). Neither heat of explosion, nor heat of combustion alone, was sufficient to establish any simple relationship with Ballistic Mortar values (Figs 4 & 5).

11. It has been shown that oxygen balance is a convenient parameter for the estimation of power of military explosives which are single compounds or mixtures of pure organic compounds (Ref K). A similar conclusion was reached using heat of explosion (Ref I). However, it appears also that oxygen balance may not be sufficient for the approximation of power of metallized explosives (Fig 6). The maximum power, as measured by the Ballistic Mortar, was given by TNT containing 20 percent of aluminum. Those metals or additives which resulted in mixtures having lower oxygen balance did not show a maximum in the region approaching zero oxygen balance. The exact point of maximum power could not be estimated because of these limited data, yet the Ballistic Mortar values were found not to vary directly as did those mixtures of pure organic compounds (Fig 7). The idealized curve was determined from existing data by the method of least squares (See Fig 50 of Ref J).

12. A relationship between oxygen balance and rate of detonation of metallized TNT also was somewhat obscure (Fig 8). It is of interest, however, that a number of the materials produced mixtures having higher rates of detonation than that produced by aluminum and TNT. The proportionality between brisance and rate of detonation for pure explosive compounds (Fig 9), was not applicable to metallized TNT mixtures. A number of additives, although giving a lower brisance than aluminum with TNT, did not depress the rate of detonation of TNT as much as aluminum. The lack of apparent correlation between readily determined or calculated explosive properties and those tests which claim to measure power, indicates that other factors not previously considered, must be involved. Extensive investigations made both by British and American workers show that the relative effectiveness of explosives detonated in an enclosed space was quite different from the effect of the same explosives detonated in the open.

13. Actual measurements of peak pressure made on cylindrical charges (3.31 inches diameter by 1.64 inch high) having equal volume (232.8 cc), gave average values shown in Table III. For purposes of comparing the relative effectiveness of these experimental charges, the data were converted to average equivalent volume and average equivalent weight (Table IV) by methods previously devised for this purpose (Ref X). A brief explanation of the method of calculation will make clear its purpose. The peak pressure-distance data of the standard explosive and the test explosives, when plotted on log-log graph paper, show the relationship in Fig 9a. The slopes of the curves generally change in a similar fashion. The relative pressure method compares the ratio of the pressure of the test explosive to the pressure of the standard explosive at each test distance. A sufficiently good approximation results from relating an average relative pressure; thus the individual

pressure ratios are averaged and comparisons are made for only one point along the curve (Fig 9a). Average equivalent weight (E.W) or average equivalent volume (EV) is defined as the ratio of the weight or volume of a standard explosive (TNT) to the weight or volume of a test explosive that will produce equal impulses or equal peak pressures at the same distance.

14. Comparison of the effectiveness of different addends to TNT (Table IV), either on the basis of average relative pressures ($\overline{K}$) or equivalent volume and equivalent weight, shows the superiority of aluminum powder over other additives. Tin appears to be worthy of further study in this respect. The precision indices of these measurements, as indicated by the standard deviation, should be improved by the use of spherical charges in future tests. However, the errors introduced seem to be consistent throughout the test and the results, therefore, are significant in comparing the contribution of different substances towards increasing the blast potential of TNT.

Part II

15. Torpex, a castable high explosive consisting of RDX, TNT and aluminum powder, was developed in England during World War II for use as a filler in warheads, mines, and depth bombs. The presence of aluminum in the mixture increases its blast effect in both air and water. Several variations in the composition of Torpex have been tested but the following are among those used in service munitions (Ref N):

	Torpex 2 Unwaxed [a]	Torpex 2 Waxed [b]	Torpex 3 [c]
RDX, %	42	41.6	41.4
TNT, %	40	39.7	39.5
Aluminum, %	18	18.0	17.9
Wax, %	--	0.7	0.7
Calcium Chloride, %	--	--	0.5

[a] Made from Composition B-2 or 60/40 Cyclotol.
[b] Made by the addition of aluminum to Composition B.
[c] Made by addition of Ca Cl_2 to Torpex 2.

The presence of wax in Torpex has the undesirable effect of (1) tending to coagulate the aluminum, thus giving a less homogeneous and more viscous product, (2) lowering the density of the cast explosive, 1.72 - 1.75 as compared with 1.66 - 1.70 obtained with waxed Torpex, and (3) lowering the compressive strength from 3700 psi to 1970 psi for waxed Torpex. However, wax is generally used in service Torpex for reasons of safety, since there is evidence that its presence lowers the sensitivity of the explosive to impact as measured by laboratory drop tests and bullet sensitivity tests of small charges (Ref N).

16. Dry Torpex possesses satisfactory stability characteristics; however, when moisture is present, there is a tendency to evolve gas due to the reaction of moisture with the aluminum. It has been shown that this gas formation can be inhibited satisfactorily by the addition of 0.5 percent calcium chloride (Ref O). Because of its insolubility and non-reactivity in case of excess moisture, silica gel was considered preferable to calcium chloride (Ref P). Storage tests have shown that if the moisture contents of Torpex 1 and Tritonal did not exceed the maximum amounts permitted by their specifications, neither explosive was affected significantly with respect to stability during 2 years' storage at 65°C (Ref Q).

17. A study of the reactivity of aluminum, magnesium and magnesium-aluminum alloy with water at room temperature over a 24-hour period, showed the following results (Ref R):

Treatment of Metal or Alloy	Wt of Sample, Grams	Action of Water Ml H_2 Evolved
Aluminum, Gd B, untreated	10	100
Magnesium, Gd A, untreated	2	36
Treated w/5% Na dichromate	10	2.4
Magnesium, Gd B, untreated	2	77
Treated w/5% Na dichromate	2	1.4
Magnesium, Gd C, untreated	10	160
Treated w/5% Na dichromate	10	0.7
50/50 Mg-Al Alloy, untreated	10	15
Treated w/5% Na dichromate[a]	10	0.4
65/35 Mg-Al Alloy, untreated	10	113
Treated w/5% Na dichromate[a]	10	0.2

[a] Dichromating solution about 100°C

It was found that the finer the granulation of the metal, the greater the reactivity with water. Thus, magnesium, Grade B, now designated as Type III, granulation No. 16 (Spec JAN-M-382A, 23 June 1949), which is 200 mesh or finer, gave 77 ml of hydrogen for a 2 gram sample, whereas magnesium, Grade C, now designated as Type II, granulation No. 14, which is 50/100 mesh, gave 32 ml of hydrogen for the same weight of sample. Magnesium, Grade A, now designated as Type I, flaked and/or chip, was comparable in granulation to Type II magnesium and gave 36 ml of hydrogen gas. Aluminum, Grade B of 100 mesh granulation, appeared to be comparable in reactivity to Grade C magnesium, although direct comparison can not be made from the above data. The magnesium-aluminum alloy was found to be much less reactive with water than either magnesium or aluminum powder alone. It is significant

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that the treatment of all these metals with a solution of sodium dichromate produced inorganic coatings which rendered the metals much less reactive with water than the untreated metals (Ref R).

18. A previous report (Ref S) notes the observation that the addition of small percentages of aluminum powder (1% of 16 micron average particle size) to high RDX content Cyclotol improved its pourability. However, viscosity determinations made with the Stormer Viscosimeter indicated an increase in viscosity with the addition of aluminum. Further work in which different granulations of aluminum were used showed that the addition of coarse aluminum (50/100) to 75/25 Cyclotol improved its pourability and reduced viscosity, whereas the addition of finer aluminum (Type C, Class C and material 100% thru 200 mesh) decreased the pourability and increased viscosity. In connection with the above studies and the study of metallized explosives, it was considered desirable to determine the maximum amount of RDX which could be added to a Torpex-type composition, containing 30 - 35 percent of aluminum, and still retain satisfactory pourability. These data, collected in Table V, show that (a) Torpex-type compositions which contain 30 - 35 percent aluminum were castable at practical temperatures and (b) the use of the special grade of coarse, atomized aluminum permitted a greater amount of RDX than the finer specification grade, Type C, Class C aluminum. Torpex-type compositions, not shown in Table V but in which higher percentages of either RDX or aluminum were used, did not produce pourable mixtures of these ingredients. Calculated blast characteristics, based on the empirical relationship with brisance (Fig 1) indicate the superiority of specification aluminum over a coarse, special granulation aluminum (Table V).

19. Inspection of the Ballistic Mortar data and the calculated power (Table VI) developed by these modified Torpex-type compositions raises doubt as to the desirability of decreasing the TNT content and increasing the percentage of aluminum at the same time. A recent study of bubble pulses from 1-lb charges of RDX/TNT/aluminum mixtures in which the percentage of aluminum was varied from 0 to 45 percent, showed that as the aluminum content increased, the bubble pressure and energy decreased (Ref U). Based on open-air blast measurements of 9-lb charges, the optimum aluminum content in the RDX/TNT/Al system was established at 20 to 28 percent, the percentage depending on whether pressure, impulse, weight or volume of charge was of interest (W). The calculated power (from Table II) when expressed in terms of percent TNT (obtained by dividing ft lbs/gm by the nRT value for TNT of 701ft-lb/gm times 100), showed that none of the variations of the Torpex formulation was comparable to standard Torpex:

Composition, % RDX/TNT/Al	Calculated Power, nRT		Observed Ballistic Mortar values, % TNT
	Al_2O_3 assumed solid, % TNT	Al_2O_3 assumed gaseous, % TNT	
w/Specification Al			
42/40/18 (Std Torpex)	141	131	128
44/26/30	106	112	105
41.8/26.2/32	93	102	111
42.1/24.9/33	94	105	104
39/26/35	90	95	100
w/Dow Special Al			
45/25/30	107	113	91
42.8/25.2/32	96	106	100
42.1/24.9/33	94	104	95
41/24/35	91	97	100

20. It is of interest to note in the above data that calculations were made assuming the metal oxide (Al_2O_3) to be either solid or gaseous at the detonation temperatures. The true values for the heat of explosion and adiabatic flame temperature may lie between the "solid" and "gaseous" values, although only standard Torpex shows the relationship of higher values for Al_2O_3 solid than Al_2O_3 gaseous. Correlation between the power, thus calculated, and the observed Ballistic Mortar values generally has shown a direct relationship on a 45° line (Ref V), but these data appear to obscure such a relationship (Fig 10). Any discrepancy which exists is believed to be due to errors in observed Ballistic Mortar values rather than to the calculated power values. In the case of Tritonals, it has been shown that the optimum percent of aluminum and the maxima of the curves (Fig 11) relative to power were in agreement with respect to both calculated nRT and Ballistic Mortar values. Calculated power values were slightly lower than the observed power, but in the range 0 to 23 percent aluminum, calculated nRT values for Al_2O_3 solid were higher than Al_2O_3 gaseous, whereas above 23 percent aluminum, the reverse was true (Fig 11). This observation for Tritonal appears to be in agreement with similar data calculated for modified Torpex-type compositions (Table VI).

21. The advantages of the thermodynamic system of calculating the power of explosives, as compared with the method for obtaining the Berthelot "characteristic product", have been described in detail (Ref V). This system takes into account the variation of the specific heat for the various

product gases over the temperature range involved. The explosion temperatures, thus calculated, are somewhat more realistic although such values may not represent true temperatures. The bases for the determination of the power or PV work product of an explosive upon detonation, is the expression

$$PV = R \cdot T \cdot \Sigma n$$

where
R = the universal gas constant or 1.987 cal/$^\circ$K/mole

T = the adiabatic flame temperature is

obtained from

$$T = 298 \neq \frac{Q_E^V}{\Sigma n C_V} \times 10^3 \text{ with}$$

Q_E^V = heat of explosion at constant volume in k cal/mole

n = number of moles of gas formed

C_V = average heat capacity in cal/mole

22. As mentioned in paragraph 18, different granulations of aluminum powder were known to affect pourability and viscosity of an explosive mixture, but little was known as to the effect on power, brisance and other explosive properties. A comparison of some results from the use of specifications grade aluminum, Dow special of coarse granulation, and a 6 micron average particle size aluminum powder is shown in Table VII. The Ballistic Mortar value of such Torpex was unaffected; however, both special granulations of aluminum caused significant decreases in impact sensitivity values, and the coarse material also lowered the brisance value. The effect on peak pressure and impulse developed by Torpex containing different granulations of aluminum must be determined by open-air blast measurements. Calculation of power as described in paragraph 21 makes no provisions for variations in particle size of the ingredients of an explosive mixture.

23. Of the other metal substitutes used in place of aluminum in Torpex, the 65/35 magnesium-aluminum alloy appears to be the most satisfactory (Table VII). The reactivity of magnesium-aluminum alloys with water is much less than that of either magnesium or aluminum powder alone and the dichromate treatment of the alloy would render this material practically inactive with respect to moisture (Paragraph 17). There was little change in the properties of the explosive mixture when a direct substitution of 65/35 Mg-Al alloy was made for the aluminum normally used (Table VII). The decrease noted in the impact sensitivity value was not sufficient to eliminate Mg-Al alloy as a suitable substitute for aluminum. The calculated nRT values shown below indicate the power obtainable from an Mg-Al alloy containing Torpex would be comparable to that of standard Torpex. The metal oxides produced should be assumed solid rather than gaseous, since the calculated adiabatic flame temperatures, when assumed gaseous, are less than the boiling points of the oxides (Table VI). Observed Ballistic Mortar values confirm the PV work product predicted for Mg-Al alloy Torpex:

Composition, % RDX/TNT/metal	Calculated Power, nRT Oxides assumed solid, % TNT	Oxides assumed gaseous, % TNT	Observed Ballistic Mortar Values, % TNT
42/40/18 Al (Std Torpex)	141	131	128
42/40/18 Mg-Al alloy	135	99	125
42/40/18 Magnesium	129	105	--

The other metallic additives gave Ballistic Mortar Values which were too low for their consideration as replacements for aluminum in Torpex.

24. Future work on Torpex-type compositions will include calculation of the PV work product of the gases of detonation to indicate the optimum proportions of the RDX/TNT/metal system which should result in maximum power. The composition thus obtained and those containing the dichromated magnesium-aluminum alloy will be tested for blast effectiveness. Open air blast measurement will also be made on compositions suggested by OCO - ORDTA in which aluminum is substituted on a volume basis for RDX of the same grist.

EXPERIMENTAL PROCEDURES:

25. The characteristics of the ingredients used in this study were as follows:

   a. RDX, Holston Lot E-2-5, about 60% of which was coarser than 50 mesh, had a calculated specific surface of approximately 500 sq cm/gm and an apparent density of 1.36 gm/cc. This material is described in detail in PA Technical Report No. 1741.

   b. TNT, Keystone Lot 2374, used in all compositions, had a solidification point of $80.5°C$ and complied with Specification JAN-T-248 for Grade I material.

   c. RDX, Type B, Class A, complied with the requirements of Specification JAN-R-398.

   d. The 65/35 magnesium-aluminum alloy, Type B, complied with the requirements of Specification JAN-M-454.

   e. Granulation of aluminum powder used:

Granulation Thru US Std Sieve No.	Specification Grade Type C, Class C	Dow Chem Co Spherical Aluminum	Special Granulation
12	--	100.0	
20	--	98.8	
40	--	83.1	
100	98.0	30.4	
200	80.0	8.0	
230	--	4.8	
325 (min)	65.0	2.9	
325 (max)	90.0	--	Avg particle size 6 micron

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26.   Preparation of High RDX Content Torpex-Type Compositions - The TNT was melted on a steam bath at approximately 95°C, aluminum and RDX were added, and the 100-gram sample was stirred while on the steam bath for at least fifteen minutes. The proportions of the ingredients were varied until the maximum amount of RDX and aluminum were added, and the resulting composition was still pourable at reasonable temperatures. Samples were poured at the lowest temperature at which they appeared to be of satisfactory fluidity. By pouring the mixtures into glass vials, 3" x 3/4", it was possible to note the fluidity of the molten mass while being cast and also to note evidences of cavitation.

27.   Cast Density - Determined with Westphal Specific Gravity Chain Balance (Mohwald Improved) Model No. A4-012 previously checked using distilled water at 20°C. Cylindrical charges, approximately 5/8" in diameter and 1½" long (obtained by breaking the above glass vials)and weighing 20-25 grams in air were used for cast density measurements.

28.   Viscosities - A modified Stormer Viscosimeter,equipped with a propeller-type rotor and with the standard cup replaced by a copper beaker, was used. Calibration was made with NBS standard viscosity samples. The copper beaker was filled with sample to a specified depth (aprx 180 gms); the rotor immersed to a mark on the shaft, and the driving weight varied until 100 revolutions were made by the rotor in thirty seconds. Temperature of the sample, maintained by circulating hot water from a thermostatically controlled bath through the sample jacket, was constant during measurements. An auxiliary bath was used to preheat the samples for thirty minutes, slightly above the test temperature, prior to viscosity determinations. The viscosity measurement of each sample was made first at 90°C and then at 85°C.

29.   Laboratory determinations of Explosion Temperature, Impact Test, 100°C Heat Test, 120°C Vacuum Stability Test and Sand Test were made by the standard procedures as described in Picatinny Arsenal Technical Report No. 1401, Revision 1, "Standard Laboratory Procedures for Sensitivity, Brisance and Stability of Explosives", A. J. Clear, 28 February 1950.

30.   The Ballistic Mortar test was made by the standard procedure described in Picatinny Arsenal Testing Manual No. 7-2, "Ballistic Mortar Test", J. M. McIvor, 8 May 1950.

31.   The rates of detonation of the cast charges having diameters of approximately 1 inch were determined by means of the high-speed rotating drum camera equipment at this Arsenal.

32.   Heat of Combustion - The double valve self-sealing Parr Bomb, No. 101 Al 202, was used for the heat of combustion; the water equivalent for this was 2779 Cal/°C. One ml of distilled water was placed in the bottom of the bomb. The bomb was flushed two times with oxygen at 10 atmospheres and filled with oxygen at 30 atmospheres pressure. A single strand of iron wire was used for ignition and a correction of 2 calories per inch was allowed. The customary titration and correction for acid was made.

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33. **Heat of Explosion** - The double valve self-sealing Parr Bomb was used. The loading density at which the determinations were made was 0.015 gm/ml. All tests of thoroughly blended powders were conducted after the bomb had been flushed twice with purified nitrogen at 10 atmospheres and then filled with nitrogen at 25 atmospheres pressure.

34. **Volume of Water at SPT** - The amount of water was determined by passing the gases, after the bomb cooled to room temperature, slowly out of the needle valve and through a weighed drying tube containing anhydrous calcium chloride. After the bomb reached atmospheric pressure, the head was dried with a small pellet of cotton which was dropped into the bomb. The bomb was closed by means of a rubber stopper fitted with a glass tube connected to a vacuum pump. This was evacuated for 15 minutes at room temperature, after which time the bomb was placed in a beaker of near boiling water and the evacuation was continued an additional 15 minutes. The hot water was replaced with near boiling water and after another 15 minutes of evacuation, the drying tube was disconnected and weighed. This process was repeated at 15 minute intervals until the drying tube had a constant weight of $\neq$ 3 milligrams.

The weight of water was calculated as follows:

$$\text{Weight of Water, gm/gm sample} = \frac{A - B}{C} - D$$

Where
A = Final weight of drying tube, grams
B = Initial weight of drying tube, grams
C = Weight of sample, grams
D = Weight of ammonium formed by sample, gm/gm

The volume of water was obtained as follows:

$$\text{Volume of Water, ml/gm} = \frac{\text{Weight of Water, gm/gm}}{18 \text{ gm/mole}} \times 22400 \text{ cc/mole}$$

35. **Open-Air Blast Tests** - Measurements of the blast characteristics of the explosive charges were made with the aid of an eight-channel oscillograph recording and calibrating unit. The cast cylindrical charges measured 8.4 cm in diameter and 4.2 cm in height, contained a 1" x 1" cylindrical cavity for a Tetryl booster and weighed approximately 3/4 of a pound. Air blast gages utilizing barium titanate crystals were standardized in the field by measuring accurately the velocity of shock waves and utilizing established relationships between velocity and peak pressure (See Ballistics Research Laboratory Report No. 336). Pressure-distance curves for TNT demolition blocks were subsequently run and checked with the theoretical and experimental results listed by Kirkwood and Brinkley in OSRD Report No. 5137 and thus gave an independent check on the accuracy of the calibration. All firings were made with six gages placed at distances of 6, 7, 8, 9, 10 and 11 feet in an improved charge suspension system at the testing range. Pressure-distance curves were obtained by enlargement of 35-mm film which recorded the trace made on the oscillograph by detonation of an explosive charge.

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INCLOSURES:

1-7   Tables Ia,b, & c thru VII
8-18 Figures 1 thru 11

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Table 1-a

Effect of Metals, Alloys or Other Addends on the Sensitivity, Stability, and Explosive Properties of TNT

Test Sample	Standard TNT	80/20 TNT/Al Tritonal*	80/20 TNT/Aluminum Borate	80/20 TNT/Aluminum Silicon 50/50	80/20 TNT/Beryllium	80/20 TNT/Boron, Amorphous	84/20 TNT/Boron Nitride	80/20 TNT/Cadmium	80/20 TNT/Calcium Silicide	80/20 TNT/Carborundum	80/20 TNT/Copper
Explosion Temperature, °C	475d	470d	490	–	400	455	160	440	410	440	435
Time, seconds	5	5	5	–	5	5	5	5	5	5	5
Impact Sensitivity, 2 Kg wt											
PA Apparatus, inches height of sample, gm	14-15 / 0.017	13 / 0.016	19 / 0.019	11 / 0.021	13 / 0.015	4 / 0.016	11 / 0.016	17 / 0.026	7 / 0.015	8 / 0.014	12 / 0.015
100°C Heat Test											
% Loss, 1st 48 hrs	0.2	0.25	1.91	0.16	0.33	0.95	1.95	0.07	0.42	0.38	0.31
% Loss, 2nd 48 hrs	0.2	0.18	0.31	0.09	0.10	0.06	0.08	0.15	0.23	0.21	0.20
Explosion in 100 hrs	None	None	None	None	None	None	None	None	None	None	None
120°C Vacuum Stability Test											
cc Gas Evolved/40.0 hrs	0.23	0.2	0.61	0.63	0.52	0.45	0.53	0.17**	0.53	0.51	1.42
200 Gram Bomb Sand Test											
Sand Crushed, gm	48.0	49.8	33.0	43.6	–	–	–	20.1	43.2	35.3	37.6
Initiator, gm Lead Azide	0.27	0.30	0.20	0.20	–	–	–	0.20	0.20	0.20	0.20
Tetryl	0.00	0.00	0.15	0.10	–	–	–	0.50	0.10	0.10	0.10
Rate of Detonation											
(Drum Camera) meters/sec Cast Density, gm/cc	7708 / 1.58-9	6475 / 1.71	6770 / 1.66	–	–	–	–	7025 / 1.61	–	6779 / 1.90	***
Ballistic Mortar, % TNT	100	124	83	–	–	–	–	83	–	80	80
Cole Blast Characteristics											
Peak Pressure	100	108	88	–	–	–	–	73	–	96	–
Positive Impulse	102	109	82	–	–	–	–	62	–	93	–
Energy	101	111	68	–	–	–	–	34	–	87	–

*Data taken from Ref 7

**100°C Vacuum Stability Test

***Detonation wave has not propagated thru charges

TABLE I-b

Effect of Metals, Alloys or Other Additives on the Sensitivity, Stability, and Explosive Properties of TNT

Test Sample	Standard TNT	80/20 TNT/Ferro Silicon	80/20 TNT/Ferro Vanadium	80/20 TNT/Mag-nesium	80/20 TNT/Mg-Al Alloy 65/35	80/20 TNT/Mg Silicide	80/20 TNT/Man-ganese	80/20 TNT/Nickel	80/20 TNT/Norite (Carbon)	80/20 TNT/Silicon	80/20 TNT/Silicon Nitride
Explosion Temperature, °C	475	430	420	420	430	-	425	425	300	430	455
Time, seconds	5	5	5	5	5	-	-	5	5	5	5
Impact Sensitivity, 2 Kg wt											
PA Apparatus, inches	14-15	7	9	9	10	-	12	11	17	10	3
Height of Sample, gm	0.017	0.016	-	0.015	0.015	-	0.015	0.015	<.017	0.015	0.017
100°C Heat Test:											
% Loss, 1st 48 hrs	0.2	0.31	0.30	0.39	0.53	0.32	0.33	0.32	1.13	0.27	0.90% gain
% Loss, 2d 48 hrs	0.2	0.13	0.20	0.35	0.51	0.07	0.13	0.10	0.38	0.07	0.17% gain
Explosion in 100 hrs	None	None	None	None	None	None	None	None	None	None	None
120°C Vacuum Stability Test:											
cc Gas Evolved in 40 hrs	0.23	0.58	0.49	0.29	0.24	0.61	0.63	0.54	114	0.79	7.25
200 Gram Bomb Sand Test:											
Sand Crushed, gm	48.0	39.9	37.8	40.9	30.0	-	38.1	37.6	34.5	38.6	-
Initiator, gm Lead Azide	0.27	0.20	0.20	0.20	0.20	-	0.24	0.20	0.20	0.20	-
Tetryl	0.00	0.10	0.07	0.10	0.10	-	0.07	0.08	0.10	0.10	-
Rate of Detonation:											
(Drum Camera) meters/sec	7708	6501	-	6260	6621	-	5926	-	5630	-	-
Cast Density, gm/cc	1.56-9	1.71	-	1.60	1.70	-	1.59	-	1.64	-	-
Ballistic Mortar, % TNT	100	85	-	105	111	-	91	<83	87	100	-
Cole Blast Characteristics:											
Peak Pressure	102	97	-	95	85	-	92	-	89	-	-
Positive Impulse	102	54	-	92	79	-	88	-	84	-	-
Energy	101	89	-	84	62	-	78	-	72	-	-

*Data taken from Ref 7

TABLE 1-e

Effect of Metals, Alloys or Other Addends on the Sensitivity, Stability, and Explosive Properties of TNT

Test Sample	Standard TNT	80/20 TNT/Steel, Stainless	80/20 TNT/Tin	80/20 TNT/Titanium	80/20 TNT/Titanium Hydride	80/20 TNT/Titanium Carbo Nitride	80/20 TNT/Titanium Dioxide	80/20 TNT/Zinc	80/20 TNT/Zirconium Hydride	80/20 TNT/Zr-Ni Alloy	80/20 TNT/Zirconium Phosphate
Explosion Temperature, °C	475d	440	430	430-30	425	430	425	420	425	420	430
Time, seconds	5	5	5	<1	5	5	5	5	5	5	5
Impact Sensitivity, 2 Kg wt											
PA Apparatus, inches	14-15	15	12	5	11	10	11	12	13	10	4
Height of Sample, cm	0.017	0.022	0.019	0.015	0.017	0.022	0.015	0.024	0.015	0.016	0.018
100°C Heat Test											
% Loss, 1st 48 hrs	0.2	—	0.29	0.29	0.28	2.67	0.33	0.45	0.30	0.30	0.30
% Loss, 2d 48 hrs	0.2	—	0.07	0.08	0.12	0.00	0.07	0.16	0.11	0.08	0.06
Explosion in 100 hrs	None	—	None	None	None	None	None	None	None	None	None
120°C Vacuum Stability Test											
cc Gas Evolved in 40 hrs	0.23	0.07**	0.56	0.56	0.45	0.12**	0.70	0.63	0.68	0.54	0.47
200 Gram Bomb Sand Test											
Sand Crushed, gm	48.0	—	40.8	—	44.2	40.4	27.0	41.4	44.7	43.4	—
Initiator, gm Lead Azide	0.27	—	0.24	—	0.20	0.26	0.20	0.28	0.20	0.30	—
Tetryl	0.00	—	0.00	—	0.05	0.00	0.10	0.00	0.10	0.00	—
Rate of Detonation											
(Drum Camera) meters/sec	7708	—	6619	—	6881	—	6737	6366	6651	6438	—
Cart Density	1.58-9	—	1.78	—	1.76	—	1.59	1.76	1.74	1.72	—
Ballistic Mortar, % TNT	100	—	111	—	100	—	90	87	87	100	—
Cole Blast Characteristics											
Peak Pressure	114	—	100	—	103	—	80	100	103	101	—
Positive Impulse	102	—	98	—	103	—	72	99	103	100	—
Energy	101	—	95	—	103	—	50	90	103	98	—

**100°C Test

* Data taken from Ref F

Table II

Thermochemical Properties of TNT and Various Addenda

80/20 Mixtures of TNT and the following Metals, Alloy or other Addend	Oxygen Balance to Carbon Dioxide**	Heat of Combustion** cal/gm Calculated	Determined	Heat of Explosion,** cal/gm Calculated	Determined	Gas Volume moles/kg Calculated	Determined	Power,** % Performance of TNT Calculated	Determined	Ballistic Mortar % TNT
No Added	-74	3615*	3612	639	689	44.2	42.8	100	100	100
Aluminum	-77	4369	4207	1802	779	24.1	30.6	155	80	124
Aluminum Borate	-70	3757								83
Aluminum Silicon	-79	4362	4245	1759	823	22.1	31.2	142	92	-
Cadmium	-62	2998	3057	677	607	33.4	34.7	81	76	< 83
Carborundum	-91	4385	3444	883	551	25.2	32.3	80	64	< 80
Copper	-64	Cu₂O 2953 CuO 3012	2993	656	579	32.1	32.8	76	68	< 80
Ferrosilicon	-72	3578	3260	1090	599	27.1	33.2	106	72	85
Ferrovanadium	-70	3396	3422	934	647	28.1	35.4	94	82	-
Magnesium	-72	4091	3828	1501	948	27.6	33.1	155	113	105
Mg-Al Alloy	-74	4189	4011	1672	1058	26.0	25.0	156	110	111
Manganese	-71	3338	3300	871	615	27.5	35.9	87	79	91
Nickel	-64	3089	3123	725	595	31.6	35.2	83	75	< 83
Norite (carbon)	-86	4456	4317	605	633	35.2	31.9	77	73	87
Silicon	-82	4354	4010	1703	600	20.5	31.2	128	67	100
Tin	-65	SnO 3004	2977	760	659	31.8	34.6	87	82	111
Titanium Hydride	-72	4063	3899	1075	703	31.2	36.3	121	92	100
Titanium Cyanonitride	-70	3751	3442	1300	510	47.1	28.0	222	51	-
Titanium Dioxide	-59	2890	2844	616	585	35.1	35.4	78	74	90
Zinc	-64	3144	2976	788	626	32.1	32.6	91	73	87
Zirconium Hydride	-66	3569	3466	840	703	35.0	32.8	106	83	87
Zr-Ni Alloy, 70/30	-66	3346	3214	964	650	31.1	33.0	108	77	100

*Calculated from structural features of the TNT molecule

**Calculated as described in Ref J

Open-Air Blast Tests of Bare Metallized TNT Charges

Lot No.	Explosive[***]	Peak Pressure in PSI at Gage Distance, Ft[*]				Average Charge Wt, gms
		6	8	9	10	
1	TNT	24.47 (7) ± 3.87	14.79(10) ± 2.35	10.21(10) ± 1.39	8.16 (9) ± 1.39	6.23 (9) ± 0.89	350.75 (10)
1a		20.13 (9) ± 0.98	10.81 (9) ± 1.01	7.78 (9) ± 0.67	5.83 (11) ± 0.62	4.90 (10) ± 0.72	346.50 (10)
2	TNT	19.03 (6) ± 1.90	10.75 (8) ± 2.30	7.85 (8) ± 1.50	6.05 (10) ± 1.21	5.16 (10) ± 1.04	345.75 (10)
2a		18.88 (8) ± 2.45	11.06(10) ± 1.17	7.36(10) ± 1.01	5.07(10) ± 0.62	4.56(10) ± 0.55	345.60 (10)
	Mean[**]	20.59(30) ± 3.31	11.94(37) ± 2.51	8.34(37) ± 1.64	6.23(39) ± 1.49	5.19(39) ± 1.00	347.15 (40)
5	80/20 TNT/Al	27.90 (3) ± 0.57	18.92 (5) ± 1.60	13.51 (8) ± 1.33	10.09 (3) ± 2.41	7.36 (8) ± 0.81	382.83 (9)
9	80/20 TNT/Si	26.37 (3) ± 0.60	16.02 (5) ± 2.05	11.00 (5) ± 1.16	7.22 (5) ± 1.10	5.38 (5) ± 1.08	369.10 (5)
11	80/20 TNT/Ni	28.03 (3) ± 0.55	19.43 (4) ± 1.04	11.98 (5) ± 1.56	7.24 (5) ± 0.82	5.52 (5) ± 1.06	403.50 (5)
15	80/20 TNT/Zn	24.30 (2) ± 0.20	16.26 (5) ± 2.99	11.72 (5) ± 0.41	8.72 (5) ± 1.18	6.20 (5) ± 0.94	405.50 (5)
16	80/20 TNT/TiO$_2$	11.06 (5) ± 1.86	8.74 (5) ± 1.78	5.54 (5) ± 1.20	4.77 (5) ± 0.17	4.90 (4) ± 0.73	393.20 (5)
17	80/20 TNT/Sn	24.20 (1) ± -	19.52 (4) ± 3.94	12.90 (5) ± 2.22	9.44 (5) ± 0.99	7.14 (5) ± 0.52	381.52 (6)
18	80/20 TNT/Cu	27.80 (1) ± -	16.85 (4) ± 4.36	10.78 (5) ± 0.66	7.11 (5) ± 0.73	5.22 (5) ± 0.94	386.00 (5)
19	80/20 TNT/SiC	22.75 (2) ± 0.85	16.17 (3) ± 0.66	9.44 (5) ± 1.89	6.52 (5) ± 1.41	5.02 (5) ± 0.76	383.90 (5)
20	80/20 TNT/FeV	24.35 (4) ± 2.49	16.34 (5) ± 2.48	9.72 (5) ± 1.08	6.34 (5) ± 1.03	5.64 (5) ± 0.75	395.80 (5)
21	80/20 TNT/Fe-Si	23.27 (3) ± 2.22	14.08 (5) ± 1.57	10.16 (5) ± 1.89	7.32 (5) ± 1.42	6.02 (5) ± 1.04	410.60 (5)
22	80/20 TNT/TiCN	-	-	-	6.55 (4) ± 0.26	4.70 (2) ± 0.10	402.63 (4)
23	80/20 TNT/C	16.10 (4) ± 3.74	11.86 (5) ± 3.00	7.58 (5) ± 1.05	5.42 (5) ± 0.79	4.38 (5) ± 0.70	356.71 (7)
25	80/20 TNT/Mn	27.45 (2) ± 1.15	12.70 (3) ± 1.69	10.18 (5) ± 2.20	7.00 (5) ± 0.84	5.53 (4) ± 0.86	378.20 (5)
26	80/20 TNT/FeSi	27.00 (1) ± -	16.23 (3) ± 0.93	11.25 (4) ± 0.85	8.58 (4) ± 0.36	6.38 (4) ± 0.48	403.70 (5)
27	80/20 TNT/Al$_2$O$_3$	21.10 (1) ± -	13.08 (4) ± 1.17	8.78 (5) ± 1.74	6.08 (5) ± 1.20	5.14 (5) ± 0.67	365.70 (5)
29	80/20 TNT/Cd	27.30 (5) ± 1.34	14.84 (5) ± 1.52	8.42 (5) ± 1.17	5.96 (5) ± 0.71	5.02 (5) ± 0.71	394.50 (5)

[*]Numbers in parenthesis indicate the number of measurements included in the calculations to give the average values reported. Dispersion of the results is shown by the standard deviation of the mean.

[**]The grand mean value of TNT used as a standard was obtained from $\text{MEAN}_{1,1a,2,2a} = \dfrac{N_1 M_1 + n_{1a} M_{1a} + n_2 M_2 + n_{2a} M_{2a}}{n_1 + n_{1a} + n_2 + n_{2a}}$ and

$$\text{Std Deviation} = \sqrt{\frac{\text{Sum of squares of all data}}{\text{total number of values}} - (\text{MEAN})^2}$$

[***](Approximately 3/4 lbs) Having constant volume

TABLE IV

Calculation of Relative Effectiveness of Metallized TNT Charges (using Data From Table III)

Test No.	Explosive	Ratios of Test Explosive to TNT at Each Distance					K̄ average	$\frac{W_{TNT}}{W_{Test}}$	K̄ standard Deviation	Average Equivalent Volume and Average Equivalent Weight of Explosive in Air		
		6 ft	7 ft	8 ft	9 ft	10 ft				$\overline{EV}$	Relative Std Error	$\overline{EW}$
5	80/20 TNT/Al	1.36 £ 0.22	1.58 £ 0.36	1.52 £ 0.36	1.52 £ 0.54	1.42 £ 0.27	1.52	0.907	£0.35	1.86	0.345	1.78
9	80/20 TNT/Si	1.28 £ 0.21	1.34 £ 0.33	1.32 £ 0.25	1.16 £ 0.30	1.04 £ 0.30	1.23	0.941	£0.23	1.37	0.342	1.29
11	80/20 TNT/Ni	1.36 £ 0.23	1.63 £ 0.35	1.44 £ 0.34	1.16 £ 0.31	1.06 £ 0.21	1.33	0.860	£0.29	1.52	0.327	1.31
15	80/20 TNT/Zn	1.18 £ 0.19	1.36 £ 0.38	1.41 £ 0.28	1.10 £ 0.38	1.19 £ 0.29	1.31	0.856	£0.30	1.48	0.344	1.20
16	80/20 TNT/ZrO2	0.73 £ 0.15	0.73 £ 0.21	0.66 £ 0.19	0.77 £ 0.19	0.94 £ 0.23	0.77	0.883	£0.19	0.57	0.371	0.59
17	80/20 TNT/Sn	1.18	1.63 £ 0.41	1.55 £ 0.41	1.52 £ 0.40	1.38 £ 0.28	1.45	0.910	£0.39	1.73	0.404	1.57
18	80/20 TNT/Cu	1.35	1.41 £ 0.47	1.29 £ 0.27	1.15 £ 0.30	1.01 £ 0.27	1.24	0.899	£0.33	1.37	0.399	1.23
19	80/20 TNT/SiC	1.10 £ 0.18	1.35 £ 0.29	1.13 £ 0.32	1.05 £ 0.34	0.97 £ 0.24	1.12	0.904	£0.27	1.19	0.362	1.08
20	80/20 TNT/P-V	1.18 £ 0.22	1.37 £ 0.35	1.17 £ 0.26	1.02 £ 0.29	1.09 £ 0.26	1.17	0.877	£0.28	1.26	0.359	1.11
21	80/20 TNT/Zr-Ni	1.13 £ 0.21	1.18 £ 0.28	1.22 £ 0.33	1.17 £ 0.36	1.16 £ 0.30	1.17	0.845	£0.30	1.26	0.384	1.06
22	80/20 TNT/TiCN	-	-	-	1.05 £ 0.25	0.91 £ 0.19	0.98	0.862	£0.22	0.97	0.336	0.84
23	80/20 TNT/C	0.78 £ 0.22	0.99 £ 0.33	0.91 £ 0.22	0.87 £ 0.24	0.84 £ 0.21	0.88	0.973	£0.24	0.83	0.410	0.81
25	80/20 TNT/An	1.33 £ 0.22	1.06 £ 0.26	1.22 £ 0.36	1.12 £ 0.22	1.07 £ 0.27	1.16	0.918	£0.27	1.26	0.350	1.16
26	80/20 TNT/PbSi	1.31	1.35 £ 0.30	1.35 £ 0.28	1.38 £ 0.33	1.23 £ 0.25	1.33	0.860	£0.29	1.52	0.327	1.31
27	80/20 TNT/AlBO3	1.02	1.10 £ 0.25	1.05 £ 0.29	0.98 £ 0.30	0.99 £ 0.23	1.03	0.949	£0.27	1.03	0.393	0.98
29	80/20 TNT/Cd	1.33 £ 0.22	1.24 £ 0.49	1.01 £ 0.24	0.96 £ 0.26	0.97 £ 0.23	1.10	0.880	£0.25	1.16	0.341	1.02

Explanation of Terms Used:

$$\overline{EV} = (\overline{K})^{3/2}, \text{ where } \overline{K} = \frac{1}{N}\sum_{i=1}^{N} K_i$$

$$K = P_{Te}/P_o$$

$$\overline{EW} = \overline{EV} \times \overline{W}_o/\overline{W}_{Test}$$

P = peak pressure
W = average weight
a subscript = constant distance
e subscript = standard (TNT)
$\overline{EV}$ = average equiv volume
$\overline{EW}$ = average equiv weight

Table V

Torpex Type Compositions Containing Maximum RDX Content
With 30 to 35 Percent Aluminum Present

Composition $ [a]	Standard Torpex II	Modified Torpex Using Specification Grade Aluminum Powder		Modified Torpex Using Specification Grade			Modified Torpex Using Special Grade of Aluminum from Dow Chem Co		
RDX, HOL Lot B-2-5	42	44	41.8	42.1	39	45	42.8	42.1	41
TNT, KEY Lot 2374	40	26	26.2	24.9	26	25	25.2	24.9	24
Aluminum, Type C, Class C	18	30	32	33	35	--	--	--	--
Aluminum, Special Grade	--	--	--	--	--	30	32	33	35
Pourability [b]									
Good or not	Good	Good	Good	Good	Good	Good	Good	Good	Good
Temperature poured, °C	80	90	90	91	85	90	93	91	90
Absolute Viscosity									
at 85°C, poises	4.5	26.5	26	83.4	59.0	20.5	22.0	41.7	47.7
at 90°C, poises	4.5	25	24	67.4	50.5	18.4	21.3	32.4	40.5
Density of Cast, gm/cc	1.77	1.83	1.85	1.93[c]	1.94	1.87	1.90	1.89	1.95
Explosion Temp, °C/5 sec	515	515	470	510	520	450	380	440	525
Impact Test, PA APP									
2 Kg weight, inches	14	16	17	17	17	9	14	11	10
Sample wt, Mg	24	22	23	24	26	23	24	26	25
Sand Test									
Sand crushed, gms	61.2	58.2	57.9	56.1	52.9	44.5	47.4	48.4	48.4
Min Detonating Charge									
Gms Tetryl	0.00	0.05	0.05	0.08	0.04	0.06	0.00	0.06	0.04
Gms Lead Azide	0.30	0.20	0.20	0.20	0.20	0.20	0.28	0.20	0.20
Ballistic Mortar									
TNT = 100, % TNT	128	105	111	105	100	91	100	95	100
Calc Blast Characteristics									
Peak pressure	124	123	123	124	120	107	112	113	114
Positive impulse	130	128	129	130	125	108	114	115	118
Energy	149	147	148	149	141	111	122	124	128

a   See Experimental Procedure for properties of the ingredients.
b   Sample poured at the minimum practical temperature at which it appeared to be most fluid.
c   Cast contained voids.

TABLE VI

Calculated Power Based on Thermodynamic Data for Modified Torpex

Composition, % RDX/TNT/Al	Molecular Wt Gas	Molar Ratio per Mole RDX/TNT/Al	Oxygen Balance	Detonation Product, Mole Al₂O₃ CO H₂ N₂ H₂O C	Heat of Comb of (H-C Gas)ₑ k cal/mole	Heat of Expl ₩ (H₂O Gas)ᵈ k cal/mole	Flame Temp, °K Quiency = T	Calc Power = R. T. Σ n k cal/mole	Calc Power = R. T. Σ n k cal/kg	ft lbs/gm ƒ

w/Specification Al

42/40/16	96.90	0.183/0.171/0.046	-54.7 /3.31	0.323 1.155 0.806 0.977 0.591 ᵏ Moles Gas = 2.938 (3.26ᵢ) ᵏ	351.8	162.6 (133.0)	5290 (4459)	30.93 (28.89)	319.2 (298.1)	985.4 (920.2)
44/26/30	70.22	0.139/0.080/0.781	-55.4 /2.43	0.391 0.141 0.537 0.617 0.836 Moles Gas = 1.295 (1.686)	285.6	162.5 (126.7)	6570 (5320)	16.91 (17.82)	240.8 (253.8)	763.3 (783.5)
41.8/26.2/32	67.11	0.126/0.077/0.797	-56.9 /2.46	0.399 0.021 0.494 0.571 0.935 Moles Gas = 1.066 (1.485)	280.2	158.5 (122.0)	6543 (5343)	14.12 (15.47)	210.4 (230.5)	640.5 (711.5)
42.1/24.9/33	65.62	0.125/0.072/0.803	-56.9 /2.34	0.0154l 0.394 0.000 0.483 0.555 0.879 Moles Gas = 1.038 (1.432)	277.0	159.9 (122.7)	6790 (5423)	14.00 (15.43)	213.3 (235.1)	658.5 (725.8)
39/26/35	62.97	0.111/0.072/0.817	-58.8 /2.32	0.0854l 0.366 0.000 0.441 0.513 0.837 Moles Gas = 0.954 (1.320)	273.1	148.4 (108.9)	6766 (5203)	12.82 (13.65)	203.6 (216.8)	628.5 (669.3)

w/DOE Special Al

45/25/30	70.18	0.142/0.077/0.781	-56.9 /2.41	0.391 0.111 0.542 0.619 0.824 Moles Gas = 1.302 (1.693)	284.7	162.6 (126.8)	6581 (5330)	17.03 (17.93)	242.7 (255.5)	749.2 (788.7)
42.8/25.2/32	67.07	0.129/0.074/0.796	-56.3 /2.36	0.398 0.024 0.498 0.572 0.881 Moles Gas = 1.094 (1.492)	279.1	162.3 (125.8)	6751 (5441)	14.68 (16.13)	218.9 (240.5)	675.7 (742.4)
42.1/24.9/33	65.62	0.125/0.072/0.803	-56.9 /2.34	0.0154l 0.394 0.000 0.483 0.555 0.879 Moles Gas = 1.038 (1.432)	277.0	159.9 (122.7)	6790 (5423)	14.00 (15.43)	213.3 (235.1)	658.5 (725.8)
41/24/35	62.93	0.116/0.067/0.817	-57.9 /2.27	0.0824l 0.367 0.000 0.449 0.516 0.817 Moles Gas = 0.96ᵘ (1.332)	271.5	149.2 (109.8)	6800 (5244)	13.04 (13.88)	207.2 (220.0)	639.⁻ (681.()

w/Other Metals

| 42/40/18 Mg/Al (65/35) | 92.59 | 0.175/0.163/0.445/ 3.217 | -52.0 /3.01 | 0.445MgO 0.109 1.256 0.770 0.933 0.410 Moles Gas= 3.02 (3.57) | 319.7 | 143.2 (80.1) | 4720 (4938) | 26.1ᵤ (20.64) | 365.9 (225.1) | 944.3 (694.9) |
| 42/40/18 Magnesium | 90.50 | 0.171/0.159/0.670 | -50.6 /2.85 | 0.670 MgO 1.310 0.752 0.911 0.316 Moles Gas = 2.97 (3.64) | 303.5 | 133.4 (80.4) | 4490 (2993) | 26.54 (21.65) | 293.3 (239.2) | 905.4 (730.7) |

d Calculated as sum of heat of combustion of each component times it molar quantity

e Calculated as Q↑ minus the energies required for complete combustion of C, CO and H₂

f 3.087 ft lbs = 1 cal

k Number in ( ) assumes Al₂O₃ as gaseous

$ % M air = $\frac{\frac{a}{MW_1} / \frac{b}{MW_2} / \frac{c}{MW_3}}{\frac{100}{100}}$

b $\frac{a}{MW_1} \sigma \frac{c}{MW_2} x \frac{MW air}{100}$

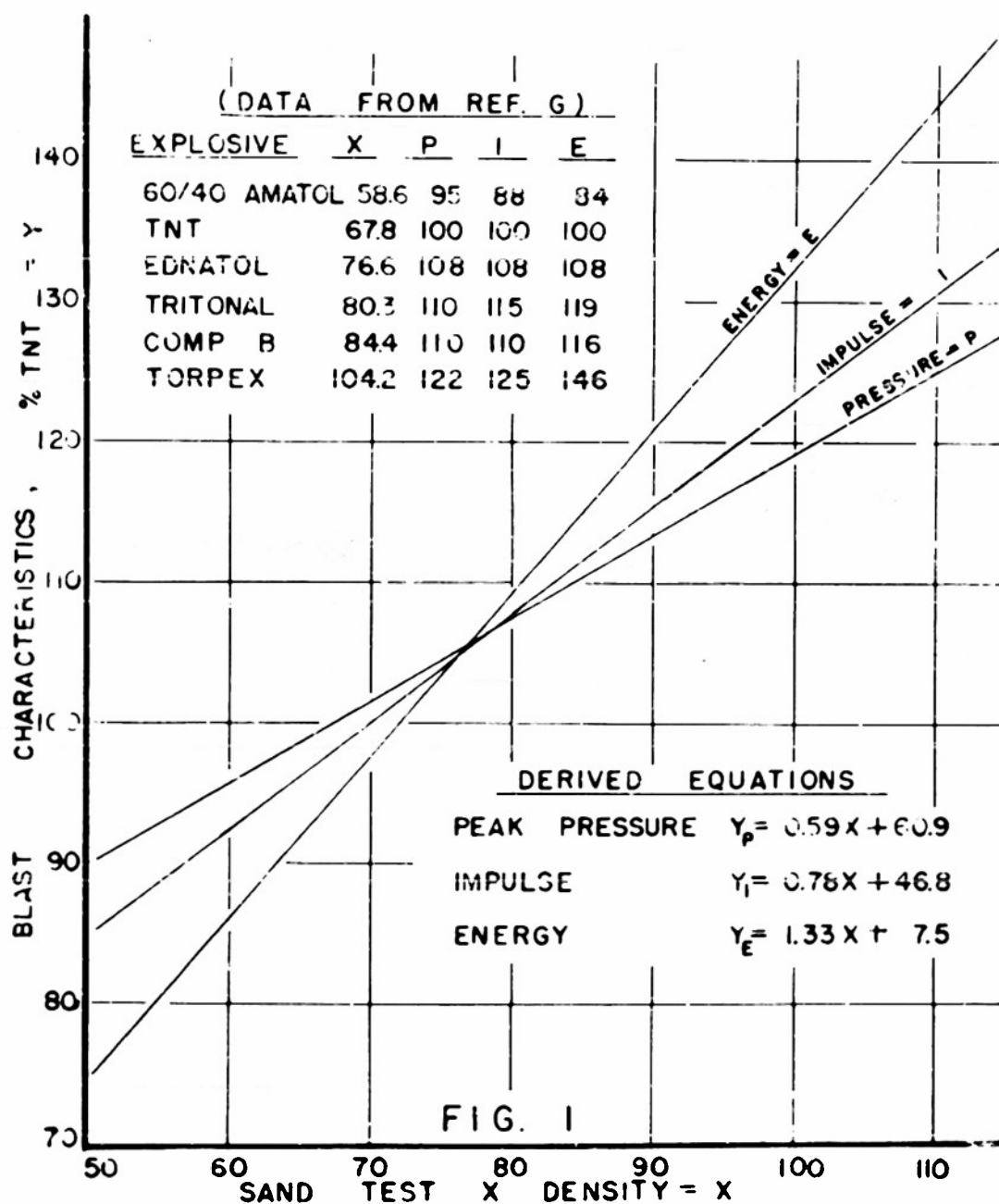c Atoms oxygen needed to burn C → CO₂, O) → CO₂ and H₂ → H₂O

Table VII

Torpex Type Compositions Containing Metal Substitutes for the Aluminum Powder Normally Used

Composition, %	Standard Torpex II	1	2	3	4	5	6	7
RDX, Type B, Class A	42	42	42	42	42	42	42	42
TNT, Key LD 2374	40	40	40	40	40	40	40	40
Aluminum	18	18	18	--	--	--	--	--
(Type)	C, CLAS C	C, Dow Special 6 Micron						
65/35 Mg-Al Alloy	--	--	--	18	18	--	--	--
Zirconium Hydride	--	--	--	--	18	--	--	--
50/50 Zr-Ni Alloy	--	--	--	--	--	18	--	--
Tin	--	--	--	--	--	--	18	--
Cadmium	--	--	--	--	--	--	--	18
Explosion Temp, °C/5 sec	515	--	--	505	375	365	270	270
Smoke, °C/5 sec	245	--	--	235	245	245	--	--
Impact Test, PA App								
2 kg wt, inches	14	6	8	9	15	11	8	6
Sample wt, mg	24	25	21	20	23	23	21	25
Sand Test								
Sand Crushed, gm	61.2	50.4	59.2	59.8	49.4	50.3	46.6	44.6
Min Detonating Charge								
Gms Tetryl	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.02
Gms Lead Azide	0.30	0.30	0.20	0.30	0.30	0.30	0.30	0.20
100°C Heat Test								
% Loss 1st 48 hrs	0.18	--	--	0.12	0.12	0.23	0.20	0.18
2d 48 hrs	0.12	--	--	0.10	0.15	0.16	0.07	0.05
120°C Vacuum Stab Test								
cc Gas evolved in 40 hrs	0.43	--	--	0.27	0.56	0.37	0.59	0.89
Ballistic Mortar Value								
TNT = 100, % TNT	128	128	128	125	111	111	105	105

EMPIRICAL RELATIONSHIP BETWEEN BLAST
CHARACTERISTICS AND SAND TEST VALUES

(DATA FROM REF. G)

EXPLOSIVE	X	P	I	E
60/40 AMATOL	58.6	95	88	84
TNT	67.8	100	100	100
EDNATOL	76.6	108	108	108
TRITONAL	80.3	110	115	119
COMP B	84.4	110	110	116
TORPEX	104.2	122	125	146

DERIVED EQUATIONS

PEAK PRESSURE $\quad Y_P = 0.59X + 60.9$

IMPULSE $\quad Y_I = 0.78X + 46.8$

ENERGY $\quad Y_E = 1.33X + 7.5$

BLAST CHARACTERISTICS, % TNT = Y

SAND TEST X DENSITY = X

FIG. I

RELATION BETWEEN CALCULATED POWER (BERTHELOT PRODUCT) AND BALLISTIC MORTAR VALUES FOR 80/20 TNT/ADDEND MIXTURES

FIG. 2
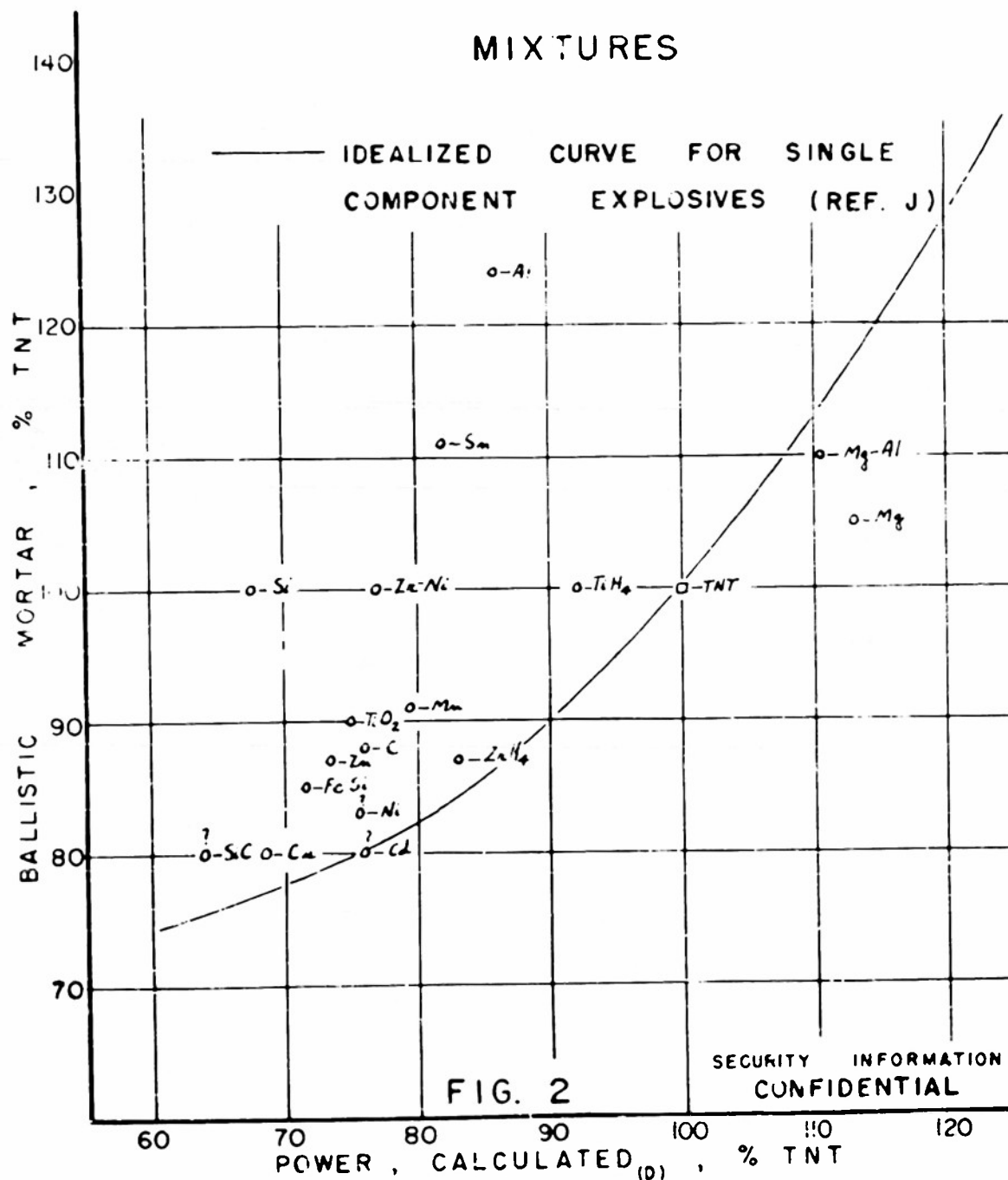
RELATION BETWEEN POWER DERIVED
FROM CALCULATED GAS VOLUME AND
CALCULATED HEAT OF EXPLOSION
(BERTHELOT PRODUCT) AND BALLISTIC
MORTAR VALUES FOR 80/20 TNT/ADDEND
MIXTURES

FIG. 3

FIG. 4
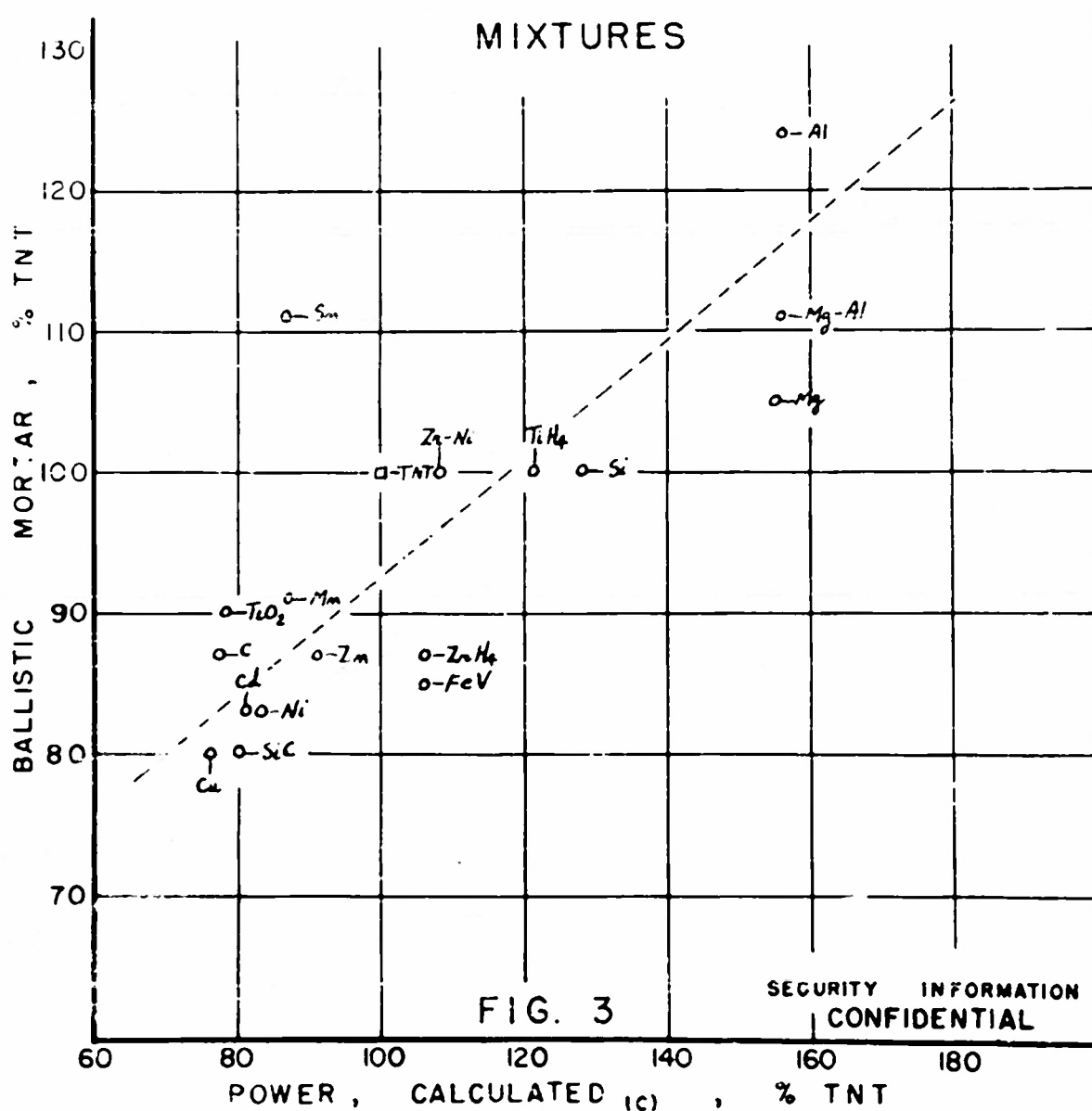
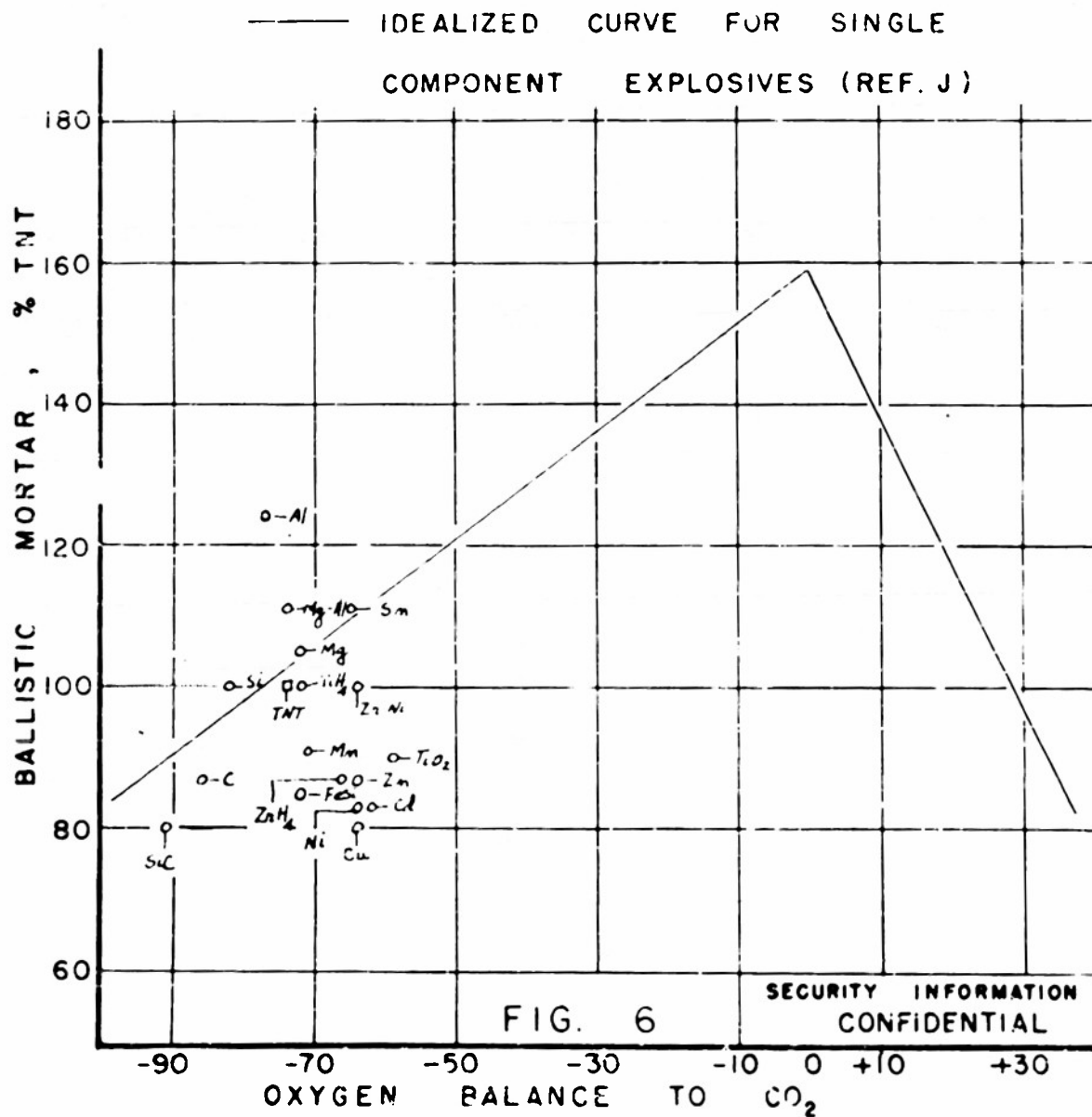RELATION BETWEEN HEAT OF EXPLOSION AND BALLISTIC MORTAR VALUES OF 80/20 TNT/ADDEND MIXTURES
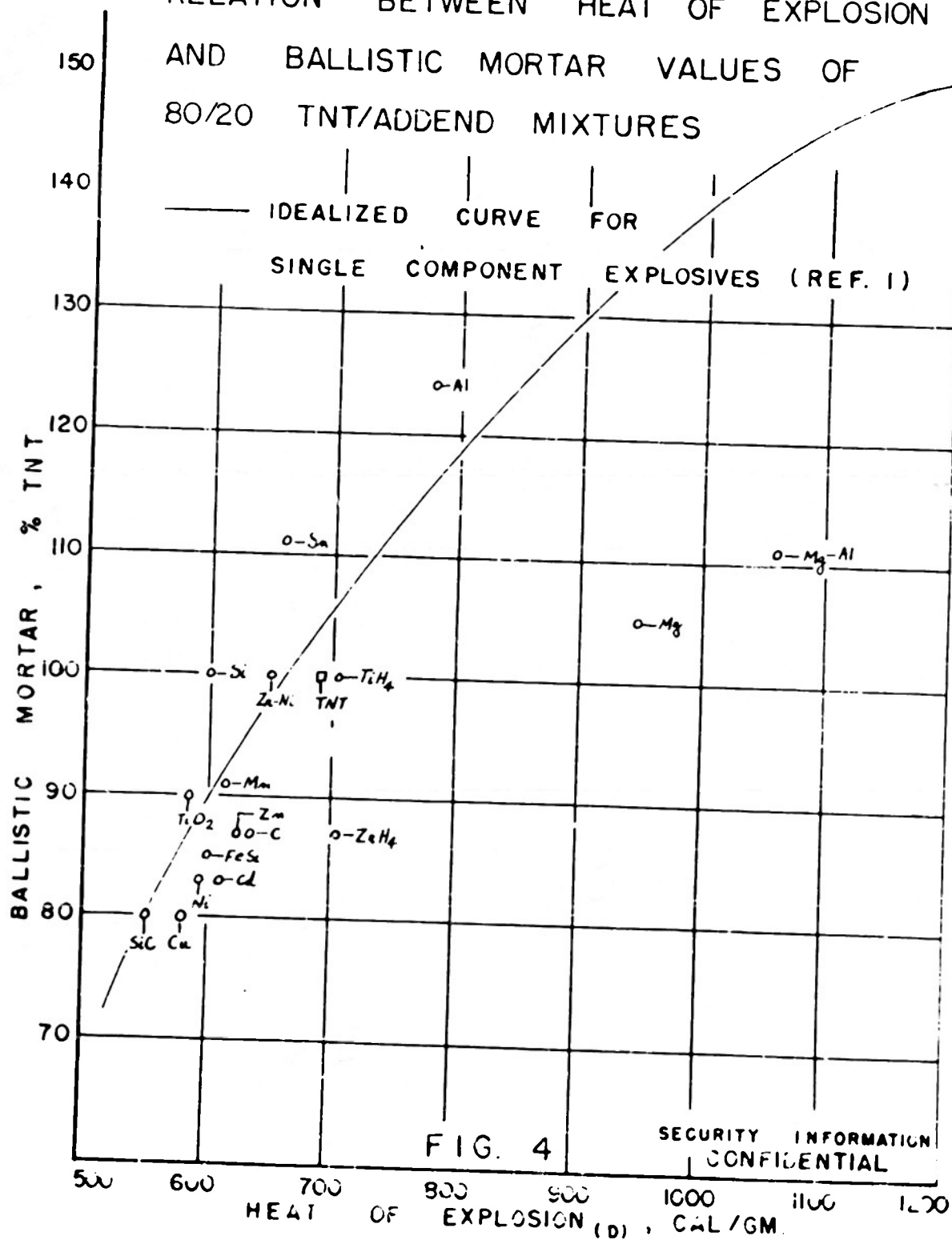
RELATION BETWEEN HEAT OF COMBUSTION
AND BALLISTIC MORTAR VALUES OF
80/20 TNT/ADDEND MIXTURES

FIG. 5

RELATION BETWEEN OXYGEN BALANCE AND
BALLISTIC MORTAR VALUES FOR
80/20 TNT/ADDEND MIXTURES

—— IDEALIZED CURVE FOR SINGLE
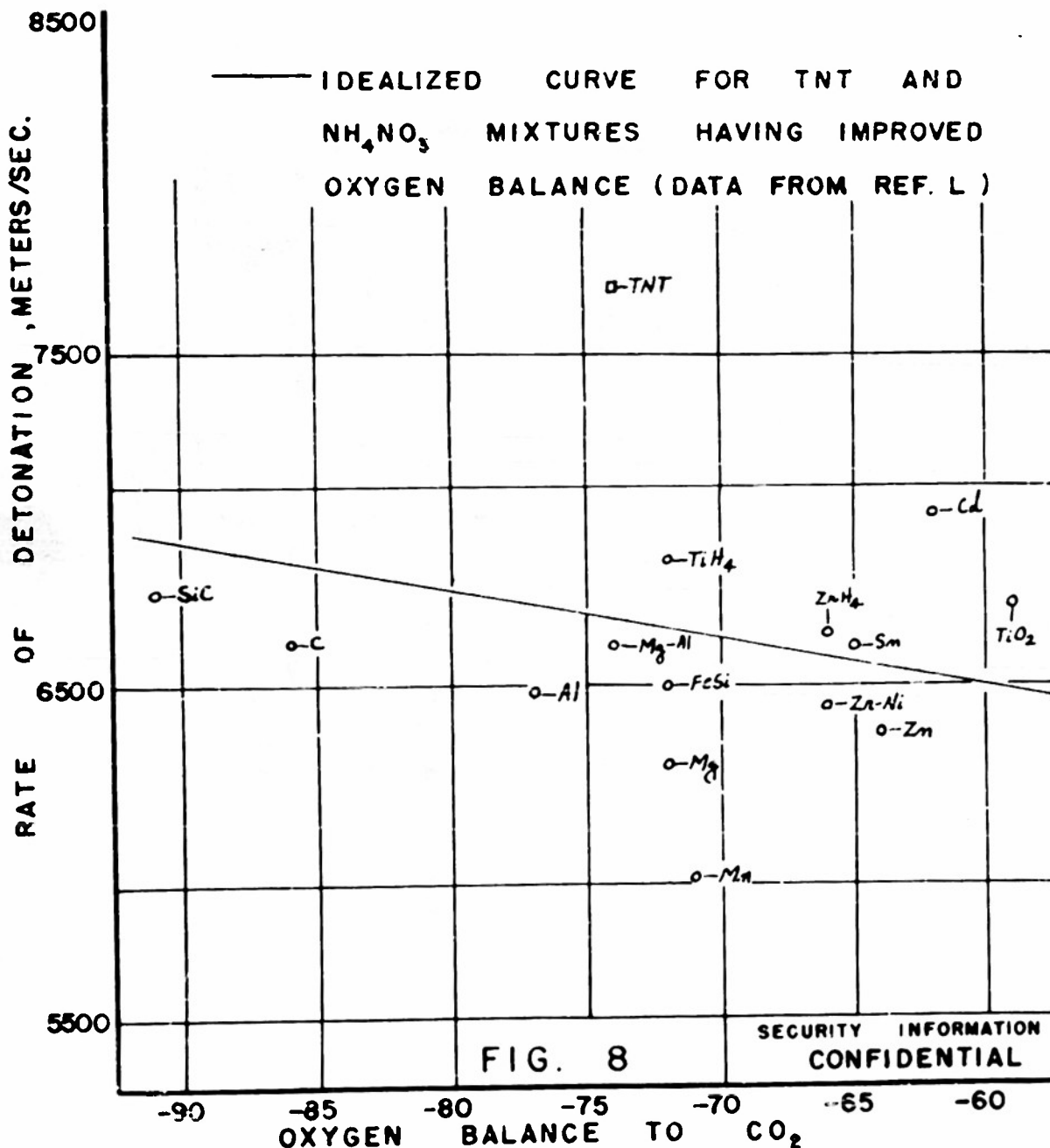
COMPONENT EXPLOSIVES (REF. J)

FIG. 6

RELATION   BETWEEN   OXYGEN   BALANCE
AND   BALLISTIC   MORTAR   VALUES   FOR
80/20   TNT/ADDEND   MIXTURES

——————   IDEALIZED   CURVE   FOR   SINGLE
COMPONENT   EXPLOSIVES   (REF. J)

FIG.   7
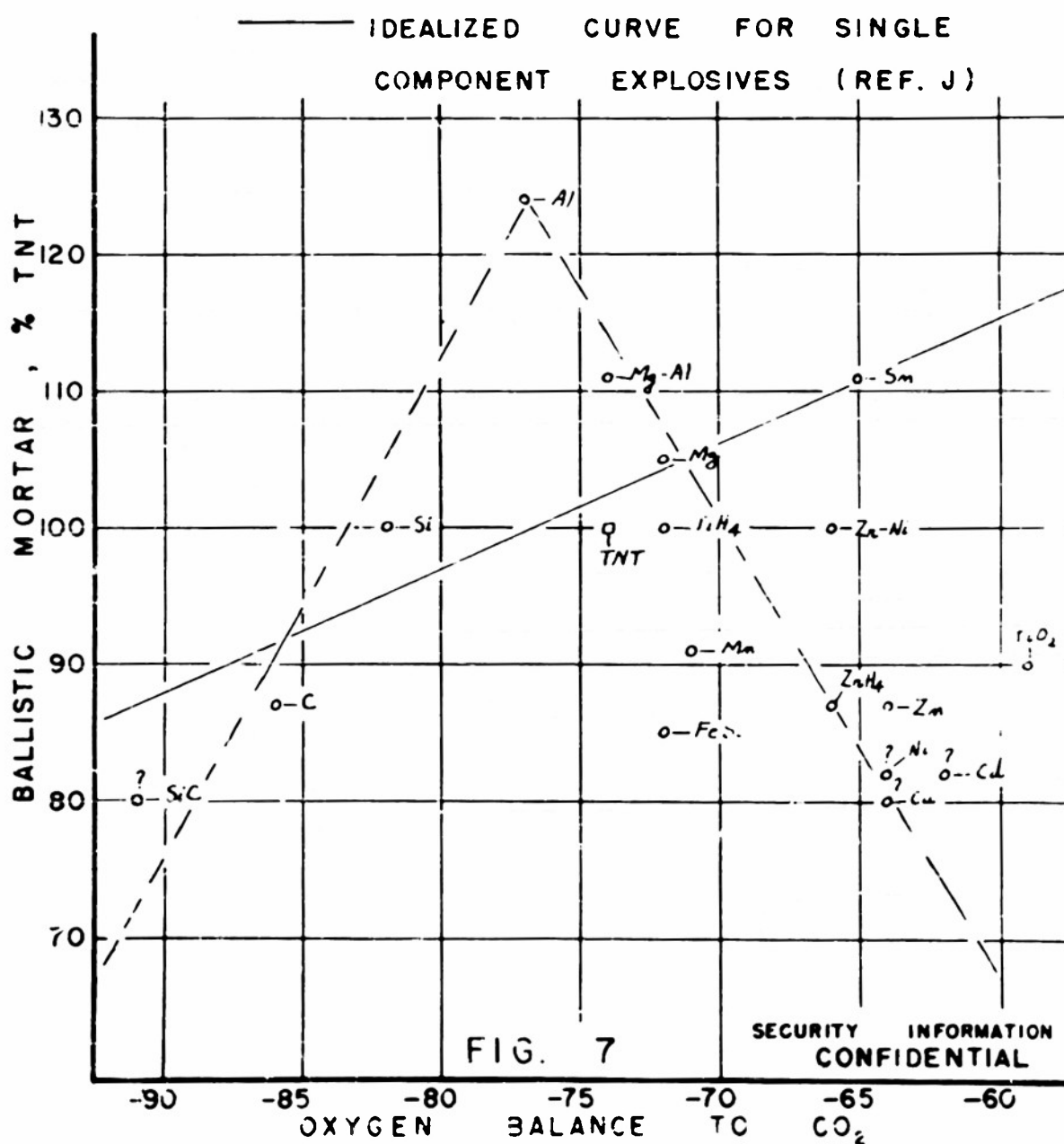
RELATION BETWEEN OXYGEN BALANCE AND RATE OF DETONATION VALUES FOR 80/20 TNT/ADDEND MIXTURES

FIG. 8

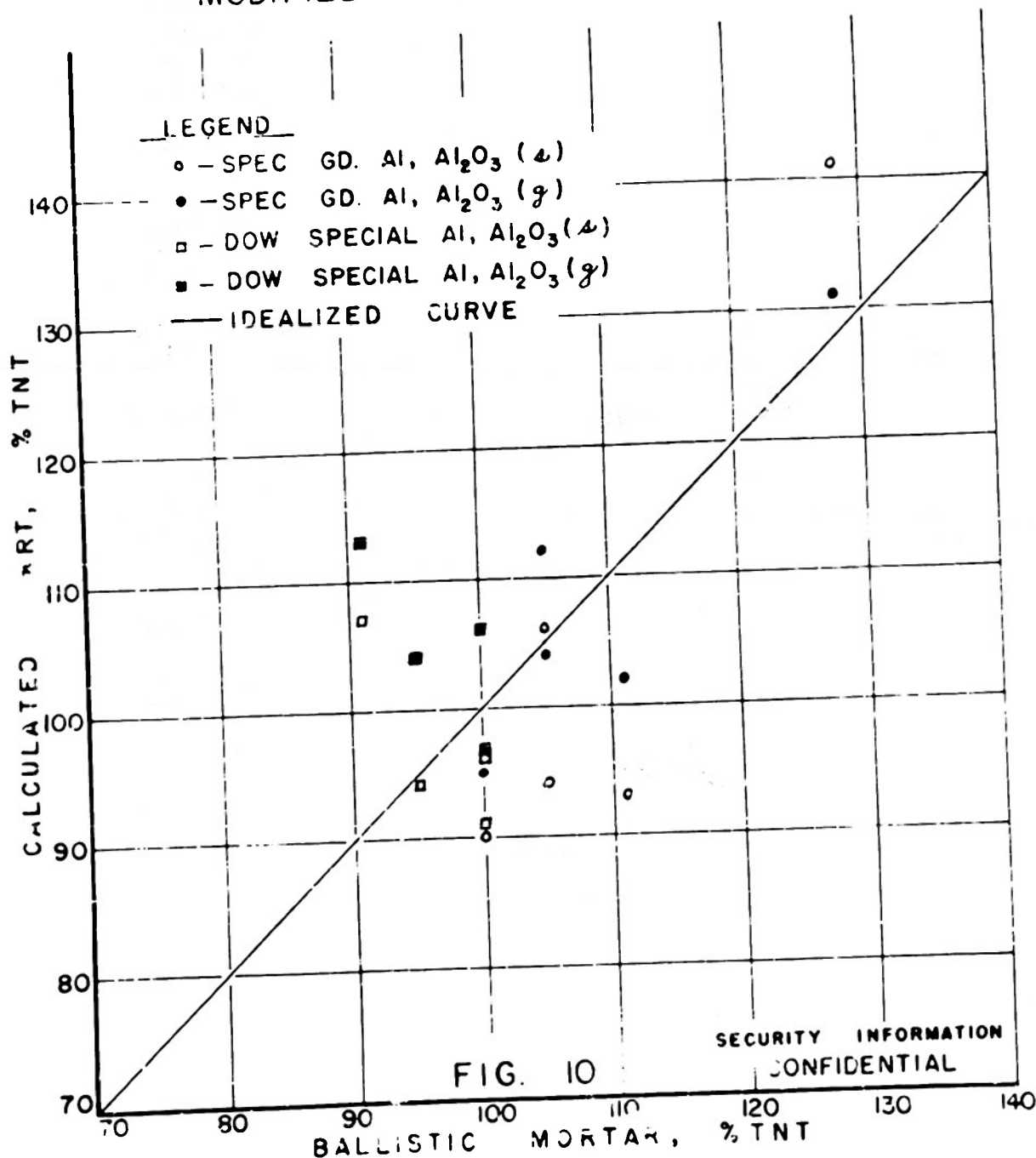# RELATION   BETWEEN   BRISANCE   AND   RATE   OF   DETONATION   OF   80/20   TNT/ADDEND   MIXTURES

FIG. 9
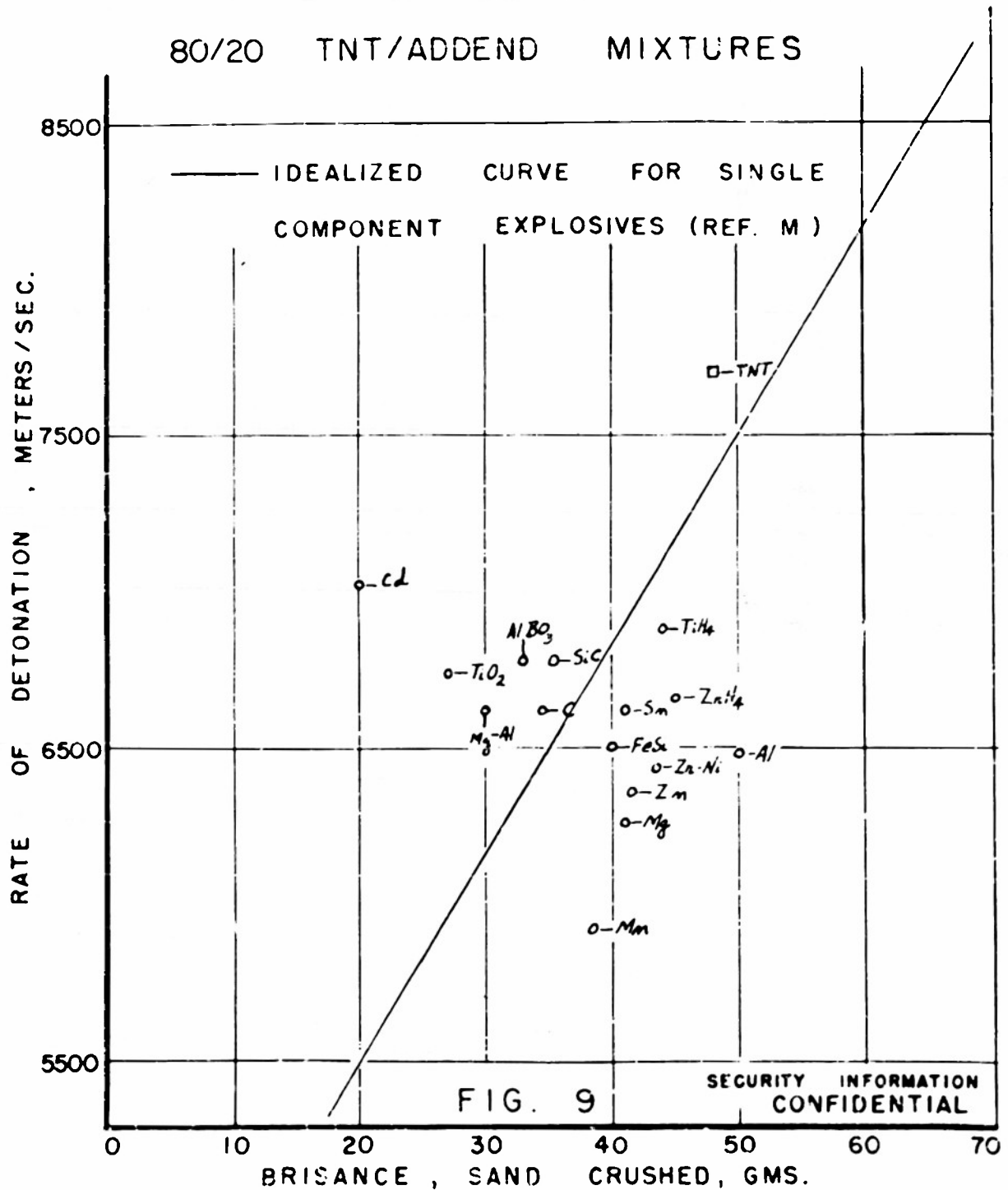
EMPIRICAL   RELATIONSHIP   BETWEEN   PEAK
PRESSURE   AND   DISTANCE   OF   BARE
EXPLOSIVES   DETONATED   IN   AIR

□ TNT (STANDARD)
· 80/20 TNT/Al.
● 80/20 TNT/CARBON

CONSTANT   PRESSURE

CONSTANT   DISTANCE

MEAN   PEAK   PRESSURE ,   PSI

FIG. 9₂

LOG   OF   TEST   DISTANCE , FEET
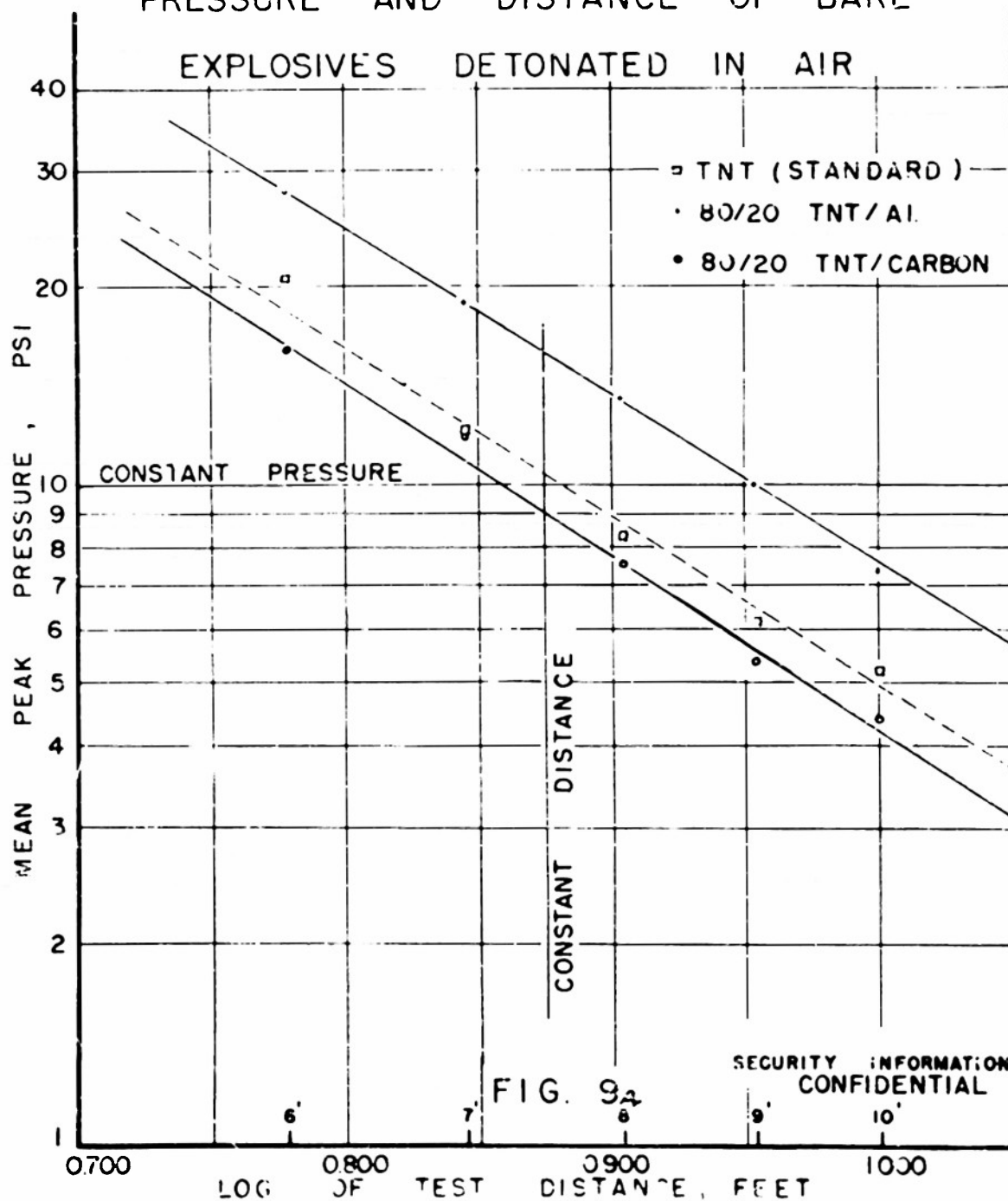
RELATIONSHIP BETWEEN CALCULATED nRT
AND BALLISTIC MORTAR VALUES FOR
MODIFIED TORPEX COMPOSITIONS

LEGEND
o — SPEC GD. Al, Al_2O_3 (α)
● — SPEC GD. Al, Al_2O_3 (g)
□ — DOW SPECIAL Al, Al_2O_3 (α)
■ — DOW SPECIAL Al, Al_2O_3 (g)
—— IDEALIZED CURVE

CALCULATED nRT, % TNT

BALLISTIC MORTAR, % TNT

FIG. 10

COMPARISON OF CALCULATED nRT POWER
WITH BALLISTIC MORTAR VALUES FOR
TRITONALS

LEGEND (DATA FROM REF. V)

● —— CALCULATED AS Al_2O_3 (α)

● ----- CALCULATED AS Al_2O_3 (γ)

○ —·—· OBSERVED BALLISTIC
MORTAR VALUES

FIG. 11